Soil temperature fluctuations in a degraded and in a reconstituted soil

Article *in* Italian Journal of Agrometeorology · December 2015

3 authors:

Paolo Manfredi
m.c.m. Ecosistemi s.r.l.

Chiara Cassinari
Ecosistemi

Marco Trevisan
Catholic University of the Sacred Heart

Soil temperature fluctuations in a degraded and in a reconstituted soil

Manfredi Paolo[1], *Cassinari Chiara*[2*], *Trevisan Marco*[2]

Abstract: *Different soils temperature fluctuations – measured in the Year 2013 – are presented. The temperatures of a natural degraded soil and a reconstituted soil – derived by a new degraded and desertified soils treatment for the restoration of fertility – are compared. The reconstitution technology, made by m.c.m. Ecosistemi research laboratory, is based on mechanical and chemical actions working on the soil structure, organic matter disposal and organic carbon policondensation. The reconstituted soils have better physical and chemical characters – including organic matter, porosity, and volumetric water content at different suctions – than the degraded one. The trend of organic matter, porosity and volumetric water content – being closely related to heat capacity, specific heat, thermal diffusivity and thermal conductivity – justify the observed thermal trend. For measuring the soils temperature – at 25 cm depth – two detection probes were used. The reconstituted soils have always less temperature fluctuations than natural one.*
Keywords: *soil temperature fluctuations; degraded soils; reconstituted soils.*

Riassunto: *Sono presentati gli andamenti delle temperature misurate in due differenti suoli: un suolo naturale tendenzialmente degradato e un suolo ricostituito – prodotto da una tecnologia di trattamento, ideata e sviluppata dal laboratorio di ricerca m.c.m. Ecosistemi, di suoli degradati e desertificati per il ripristino della loro fertilità. Tale trattamento si basa sulla produzione di neoaggregati di suolo mediante azioni meccaniche e chimiche che agiscono sulla struttura del terreno, sulla disposizione della sostanza organica all'interno degli aggregati e sulla policondensazione del carbonio organico. L'andamento di parametri quali il contenuto in sostanza organica, la porosità e i contenuti idrici, essendo strettamente legati alla capacità termica, al calore specifico, alla diffusività termica e alla conducibilità termica giustificano il differente andamento termico osservato. Le terre ricostituite hanno sempre temperature più costanti, inferiori nel periodo estivo e superiori in quello invernale rispetto ai suoli naturali di confronto.*
Parole chiave: *andamento termico dei suoli; suoli degradati; suoli ricostituiti.*

1. INTRODUCTION

Agricoltural soil is a complex, dynamic and living system where biological processes continuously take place. The term soil, as used by engineers, refers to a complicated material consisting of solid particles of various compositions (mineral and/or organic) and various shapes and size that are randomly arranged with pore spaces between them – the soil structure. The pores contain air and water in its various phases as vapor, liquid or ice. The water may also contain mineral salts and ions (Farouki, 1981). Soil is a non-renewable resource, which may be subject to degradation processes related to anthropisation (Floccia and Jacomini, 2012). The Thematic Strategy for Soil Protection identifies eight threats that compromise soil functions: compaction, contamination, erosion, loss of organic matter, sealing, salinization, loss of biodiversity and desertification (the final stage of degradation). The United Nations Convention to Combat Desertification defines desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (United Nations General Assembly A/AC 241/27, 1994). Soil degradation affects other aspects of more general interest: water, health, climate, nature protection and food safety (CE 2006).

The decreasing of soil structure, organic matter, porosity, hydraulic and thermal conductivity, and of ability in maintaining chemical and biological functions are some of the effects of soil degradation (Perini *et al.*, 2008). Soil desertification – the extreme form of soil degradation – is the result of a complex interaction system irreversibly affecting the productive capacity of natural, agricultural and forestry ecosystems (Perini *et al.*, 2008). In the last years the soil degradation and

* Corresponding author's e-mail: chiara.cassinari@unicatt.it
[1] m.c.m. Ecosistemi s.r.l. Gariga di Podenzano, Piacenza, Italia.
[2] Istituto di Chimica Agraria ed Ambientale, Università Cattolica del Sacro Cuore sede di Piacenza, Italia.
Received 28 January 2015, accepted 25 May 2015

desertification are so rapidly increasing that the strategies to fight them are the most important issues in the financing projects. According to the European Commission the land degradation is affecting in a different way the whole World (EC, 2006 b) and the European Environment Agency (EEA) 2010 report shows that the land degradation is increasing in spite of the engagements made to prevent it (EC, 2012). Soil degradation and desertification are affecting, in different way, all the countries bordering the Mediterranean Sea, causing a progressive loss of soil biodiversity (MATTM, 2010). Perini *et al.*, 2008 identified an ecological degradation with significant sensitivity to desertification for about 30% of Italian soils.

This paper is part of a Life+ project – New Life project (*http://www.lifeplusecosistemi.eu*) – whose aim is the fight against the land degradation. The New Life project "Environmental recovery of degraded soils and desertified by a new treatment technology for land reconstruction" (Life 10 ENV/IT/000400 "New Life") – co-financed by the European Union – is testing an innovative technology for restoring soils. This technology is a chemical-mechanical system (owned by mcm Ecosistemi s.r.l.) applied to degraded and desertified soils, which improves the structure increasing organic matter in soil aggregates. The technology makes a new soil called reconstituted soil, which has better chemical-physical characters than the degraded one from which it is built, determining an increase in soil fertility after the treatment (Manfredi *et al.*, 2012).

The first prototype (performed in Year 2008) of reconstituted soils is located in a farm near Piacenza - Gossolengo. In this farm the reconstituted soil was monitored for phisicochemical characters and it has been compared with natural one. In particular the investigation showed:

- Change in the structure from poor soils aggregates, indicating lack of organic matter, to grainy structures allowing an optimal gas, liquid and solid phase exchange, higher porosity and lower density;
- Greater holding water capacity and higher water availability for crops, allowing a saving irrigation, as demonstrated by Manfredi *et al.*, 2012;
- Higher nitrogen concentration;
- Higher organic carbon concentration;
- Lower pH;
- Lower total limestone;
- Different thermal properties.

This paper focuses on thermal soil properties and the results of temperature measurements – performed in the Year 2013 – in a degraded and reconstituted soil are presented. The compared soils, managed in the same agronomic way, are different for chemical-physical characters. The aim of this paper is to show how the reconstitution technology acts on improvement of thermal properties.

The soil temperature is a very important physical factor both for plants – influencing their development, growth and spread of the nutrients – and for the soil characters itself – influencing the organic matter decomposition rate, the soil structure and water movement (Tenge, 1998). The organic matter mineralization depends on its nature, abundance and climatic factors – temperature and humidity – affecting microbiological soil activity (Leiros, 1999).

The temperature changes with the depth and the radiant and latent heat. The thermal fluctuations follow diurnal cycles – soil as an "energy sink" during the day and "energy source" during the night (Abdul Rahim *et al.*, 1986) – and annual cycles – resulting from the variations of the radiation shortwave throughout the Year. The diurnal and seasonal temperature fluctuations can be mathematically described as a sinusoidal function of time around an average temperature (Lal and Shukla, 2004).

The soil thermal properties are ruled by thermal characters (De Vries, 1963). The thermal diffusivity – the speed of acquired heat to spread – is directly proportional to the thermal conductivity, and inversely to the heat capacity. The thermal conductivity is the speed transferring heat from one particle to another. It depends on the ratio of solids, water and gases in the soil; air has a much lower thermal diffusivity of water and solid. High air content reduces the thermal contacts between the soil particles reducing the conductivity. An increase in bulk density – decrease in porosity – leads to an increase in the thermal conductivity mainly due to: more solid matter and less pore air or water per unit soil volume, better heat transfer across the contacts (Farouki, 1981).

The thermal capacity is the heat amount retained by the soil layers. It depends on several factors, some related to the soil characters itself, and other controlled by external factors. Among the soil properties they are the mineralogical com-

position and the organic matter (Wierenga *et al.*, 1969). The other factors include the water content and the density (De Vries, 1952, Wierenga *et al.*, 1969; Yadav and Saxena, 1973). The water content is very important but it is difficult to control, depending on the weather conditions. The soil management influences the heat capacity because it can cause compaction, thus increasing the bulk density and decrease the porosity (Nidal, 2003).
With the same mineralogical component and weather conditions a greater or lower organic matter amount, porosity – increasing with the organic matter – and bulk density determine different thermal diffusivity. These characters – very different in reconstituted soils and degraded soils – can justify the observed thermal fluctuations.

2. MATERIALS AND METHODS

The study area is located in a farm in Gossolengo, Piacenza, Italy. The reconstituted and natural soils are divided in 2 plots, 3 ha each one (Fig. 1). The reconstituted soil, performed in Year 2008, was made from the natural degraded farm soil. Both the soils are managed in the same way (harrowing, plowing, sowing).
The samples for chemical-physical analysis were taken at 30 cm depth. For chemical analysis 3 subsamples in parallel transects were sampled; in Fig. 1 sampling points: 1-2-3 natural soil, 1A-2A-3A-4A reconstituted one. For physical analysis undisturbed soils samples were collected by auger sampler ring.
Chemical and physical analyses were carried out based on the Methods of Soil Chemical and Physical Analysis as described in the Official Gazette of the Italian Republic: texture and grain size (Italian position Method II.5 Suppl. Ord. G.U. n° 248/21.10.1999; international position ISO 11277), bulk density (Italian position Method II.1, Suppl. Ord. G.U. n° 173 del 02.09.1997; international position ISO/DIS 11272); particle density (Italian unofficial Method II.2, international position ISO/DIS 11508); organic carbon (Italian position Method VII.3, Suppl. Ord. G.U. n° 248/21.10.1999, Walkley-Black,), water potential (Italian position Method VIII.3, Suppl. Ord. G.U. n° 173/02.09.1997, international position ISO /DIS 11274, sand box and Richards plates; measurements performed on undisturbed samples); porosity is calculated by bulk density and particle density. For measuring the soils temperature, at 25 cm depth, two detection probes (AHLBORN ALMEMO 2390-8), located in position 1 and 1A Fig. 1, were used; both connected to a data logger that took data every 10 minutes.

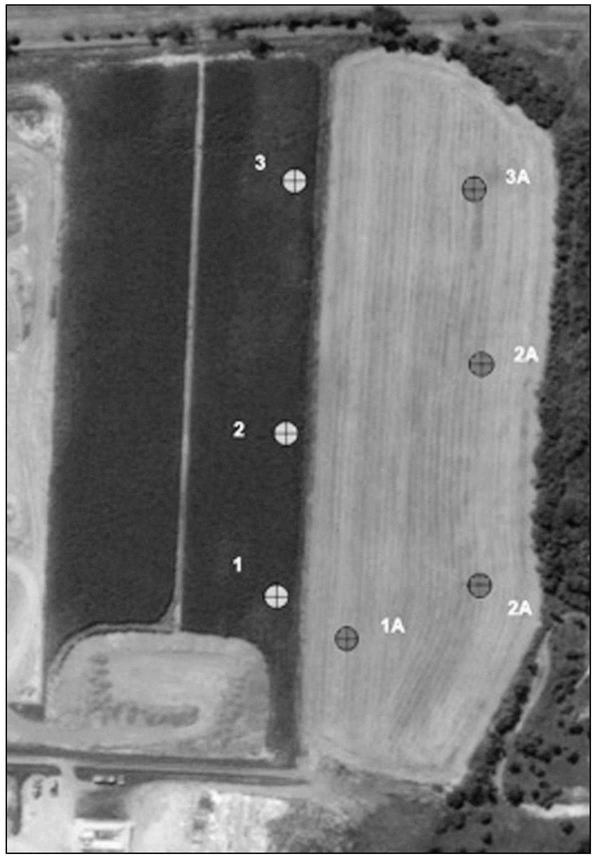

Fig. 1 - Study area; sampling points: 1-2-3 in natural soil; 1A-2A-3A-4A in reconstituted one.
Fig. 1 - Area di studio; punti di campionamento: 1-2-3 suolo naturale; 1A-2A-3A-4A *suolo ricostituito.*

3. RESULTS

In Tab. 1 the data of air temperature and rain from and January 2013 to January 2014 – by Azienda Sperimentale "Vittorio Tadini", Piacenza, Italy weather station – were shown. The mean temperature was 12.5 °C, total rain (747.2 mm), mostly fell in March, April, May and November; while in February there was no rain. March was the month with most days of rain (26 days), while May had most amount of rainfall (149.2 mm). February was the coldest month – mean temperature 2 °C, max temperature 11.8 °C, min temperature -5.4 °C. The lowest temperature -5.8 °C was detected in January 23, 2013. July was the hottest month – mean tem-

mounth	Temperature			rain	Days of rain	More Rainy day
	mean	max	min			
	°C	°C	°C	mm	n	
January	2.1	13.9	-5.8	11.2	7	2
February	2	11.8	-5.4	0	0	
March	6.3	17.2	-5.1	63.7	26	6
April	13.2	26.6	3	120.8	16	5
May	16.2	26.3	6.1	149.2	17	25
June	21.7	35.3	10.6	20.2	5	27
July	25.5	37.1	14.9	6	4	8
August	23.9	35.4	13.8	39.6	8	26
September	19.9	31.4	9.6	35.4	6	15
October	14.5	22.8	6.6	94	20	7
November	8.4	19	-3.3	67.8	19	15
December	3.3	13.1	-3.8	26.3	23	26
January 2014	5.3	12.3	-1.6	113	22	30

Tab. 1 - Year 2013: temperature and rain measured at Azienda Sperimentale "Vittorio Tadini" in Podenzano (Pc).
Tab. 1 - Temperatura, precipitazioni relative all'anno 2013 rilevate presso la stazione meteo dell'Azienda Sperimentale "Vittorio Tadini" sita a Podenzano (Pc).

perature 25.5 °C, max temperature 37.1 °C, min temperature 14.9 °C, while the hottest temperature 37.1 °C was in July 28.
In Tab. 2 the chemical-physical soils parameters were shown; the natural and reconstituted investigated soils were very different. The reconstituted soil had the bulk density (1.08gcm^{-3}) and the particle density (2.14 gcm^{-3}) lower than the

sample	Sand	Clay	Silt	Bulk density	Particle density	Porosity	Organic Carbon	Salinity
	gkg^{-1}	gkg^{-1}	gkg^{-1}	gcm^{-3}	gcm^{-3}	%	gkg^{-1}	dSm^{-1}
natural soil 1	403	150	447	1.86	2.29	19	12.89	0.32
natural soil 2	317	160	523	1.53	2.41	37	11.80	0.21
natural soil 3	344	130	526	1.54	2.56	40	11.73	0.24
natural soils:								
mean	**355**	**147**	**498**	**1.64**	**2.42**	**32**	**12.14**	**0.26**
standard deviation	**44.0**	**15.3**	**44.8**	**0.2**	**0.1**	**11.4**	**0.7**	**0.1**
reconstituted soil 1	203	175	622	1.15	2.08	45	44.75	0.36
reconstituted soil 2	395	27	578	1.11	2.10	47	44.37	0.71
reconstituted soil 3	374	195	432	0.99	2.26	56	48.34	0.91
reconstituted soil 4	348	33	619	1.08	2.12	49	38.16	1.23
reconstituted soils:								
mean	**330**	**107**	**563**	**1.08**	**2.14**	**49**	**43.90**	**0.80**
standard deviation	**86.8**	**89.9**	**89.4**	**0.1**	**0.1**	**4.8**	**4.2**	**0.4**

Tab. 2 - Soils chemical-physical analysis.
Tab. 2 - Esiti delle analisi chimico-fisiche.

sample	Suction (-kPa)			Available Water
	0.1	31	1500	
natural soil 1	44.60	36.09	31.29	4.79
natural soil 2	48.31	35.94	30.19	5.75
natural soil 3	49.99	34.06	29.24	4.83
natural soils				
mean	**47.64**	**35.36**	**30.24**	**5.12**
standard deviation	**2.8**	**1.1**	**1.0**	**0.5**
reconstituted soil 1	60.72	46.78	40.45	6.33
reconstituted soil 2	71.42	33.87	26.00	7.87
reconstituted soil 3	74.69	39.51	32.79	6.72
reconstituted soil 4	71.51	40.07	33.17	6.90
reconstituted soils				
mean	**69.58**	**40.06**	**33.10**	**6.96**
standard deviation	**6.1**	**5.3**	**5.9**	**0.7**

Tab. 3 - Volumetric water content (θ%) at different suction and available water.
Tab. 3 - Contenuto volumetrico di acqua (θ%) ai diversi valori di suzione e acqua disponibile.

natural one (1.64 gcm^{-3} and 2.42 gcm^{-3}, respectively) while the porosity percentage increased (49 % vs 32 %). The organic carbon content of reconstituted soil was 4 times higher (43.9 gkg^{-1}) than in natural one (12.1 gkg^{-1}), because the natural soil was compacted, the physical and chemical parameters were degradated and it was characterized by low fertility.
In Tab. 3 the volumetric water content (θ%) at different suctions (0.10 kPa; 31 kPa; 1500 kPa) and the available water content (difference between 31 kPa θ% and 1500 kPa θ%) were shown. The volumetric water content of reconstituted soil was higher than natural one for all the suctions. The volumetric water content at field capacity increased from 35.36 θ% in the natural soil to 40.06 θ% in the reconstituted soil, in which the volumetric water content at wilting point was higher in the reconstituted soil (33.10 θ%) than that in the natural soil (30.24 θ%) as well as the available water (6.96 θ% and 5.12 θ% in the reconstituted and natural soil respectively).
ANOVA (IBM SPSS version 21) was performed on the chemical-physical data. By ANOVA they were statistical different: the bulk density values (lower in reconstituted soil than in natural one) p-value = 0.02, < 0.05, the particle density values (lower in reconstituted soil than in natural one) p-value = 0.018, < 0.05; and the organic carbon content (greater in reconstituted soil than in natural one) p-value = 0.00, < 0.01. The porosity (calculated from the bulk density and particle density) is, therefore, statistical different p-value = 0.038, < 0.05. Also the water retention capacity is statistical different (greater in reconstituted soil than natural one): the volumetric water content at the 0.1 kPa suction p-value = 0.002, < 0.01 and the available water p-value 0.011 <0.05.
The soils temperature data were related to about 10 days in the months of February, May, July, August, November, December and January 2013. Soil temperature fluctuations showed that the reconstituted soil had lower temperatures in summer and higher in winter than natural one. The soil temperature fluctuations during the day-night cycles in soils are larger in natural than in reconstituted one.
In February, in the days relating to thermal reliefs in soils, the mean air temperature was 2.1 °C, max temperature 11.8 °C, min temperature -1.8 °C; there was no rain. In Fig. 2 the two thermal soils curves were compared. The mean temperature of the reconstituted soil was 3.8 °C while in the natural soil 2.6 °C, with a thermal excursion of 0.2 °C in the reconstituted soil and 0.5 °C in the natural one.
In the days relating to thermal reliefs in soils in May the mean air temperature was 17.6 °C, max temperature 25.3 °C, min temperature 9.2 °C; 9 days of rain with a total of 38 mm rain. In Fig. 3 the thermal curves of the two soils were presented, the excursion between day and night was much more in the natural soil (mean day-night excursion 2.3 °C) than in the reconstituted one (mean day-night excursion 0.5 °C). The average temperature was in the reconstituted soil 17.2 °C

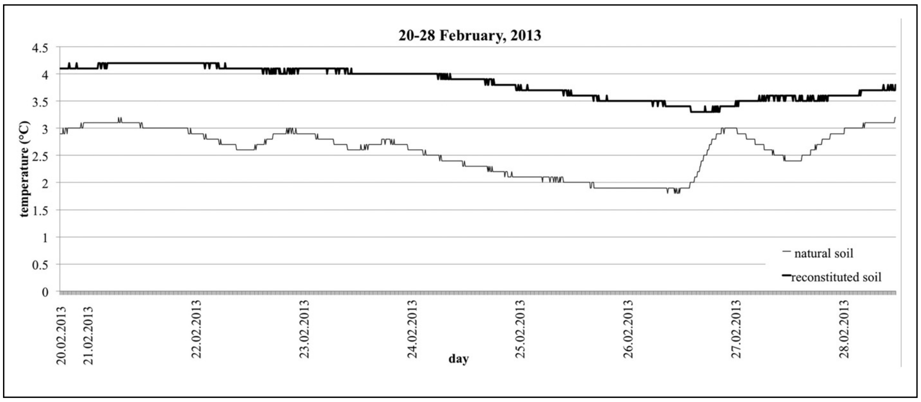

Fig. 2 - Soil temperature fluctuation in February.
Fig. 2 - Andamento temperature nel mese di febbraio.

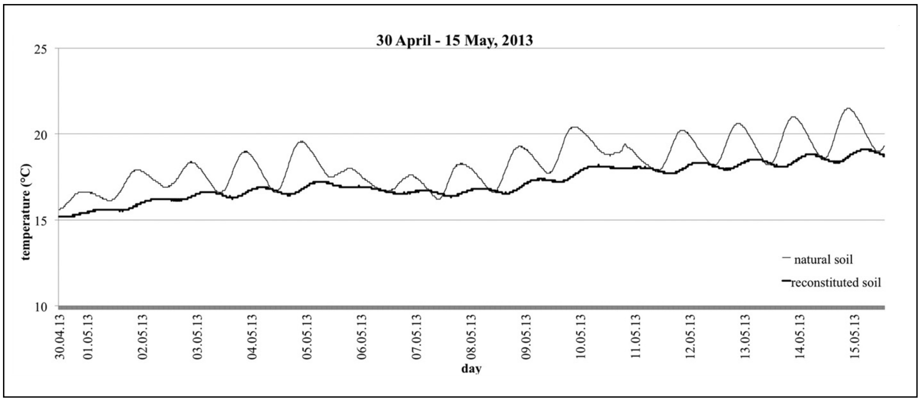

Fig. 3 - Soil temperature fluctuation in May.
Fig. 3 - Andamento temperature nel mese di maggio.

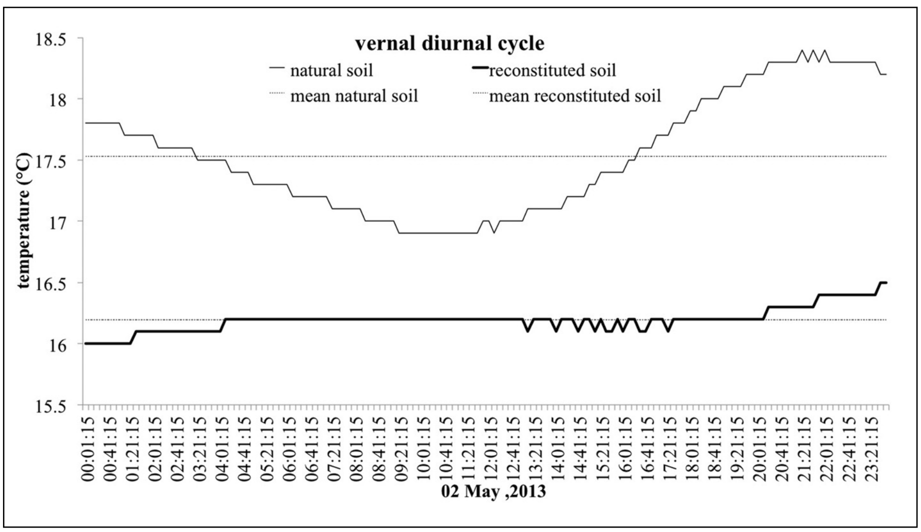

Fig. 4 - Soil vernal diurnal cycle.
Fig. 4 - Ciclo diurno primaverile.

and in the natural soil 18.3 °C. In Fig. 4 the soil vernal diurnal cycle referring to May, 2; the different soils trends near their mean day temperature value were clearly visible. On May, 2, it rained 2.4 mm that could have influenced the amplitude of temperature variation but only in natural soil.

In August, in the studied days, the mean air temperature was 24.5 °C, max temperature 33.9 °C, min temperature 17.2 °C; 2 days of rain with a total of 8.8 mm rain. Fig. 5 describes the thermal curves of the soils. In August the reconstituted soil mean temperature was 22.4 °C and thermal excursion 1 °C, the natural soil mean

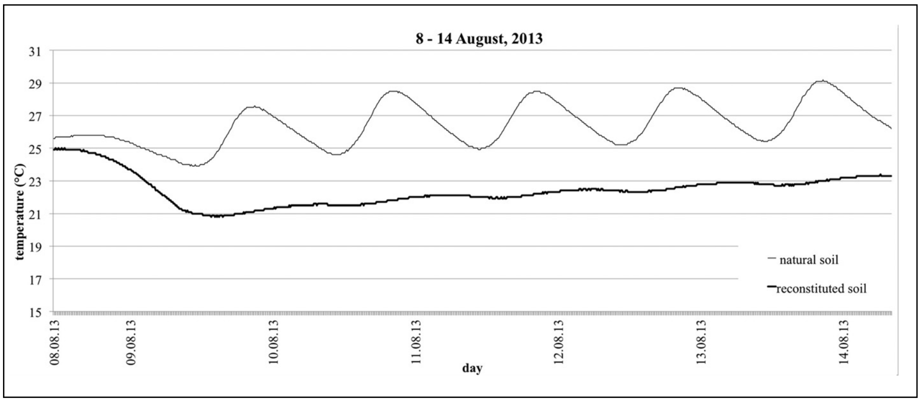

Fig. 5 - Soil temperature fluctuation in August.
Fig. 5 - Andamento temperature nel mese di agosto.

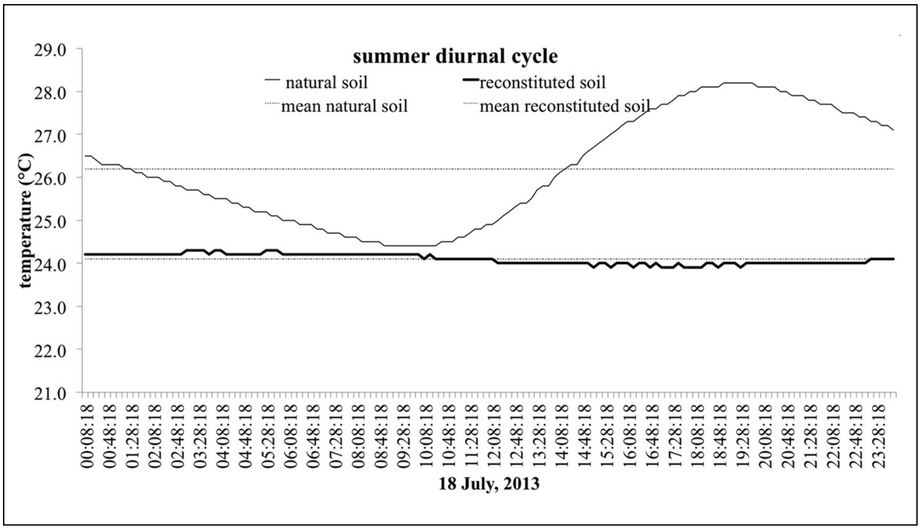

Fig. 6 - Soil summer diurnal cycle.
Fig. 6 - Ciclo diurno estivo.

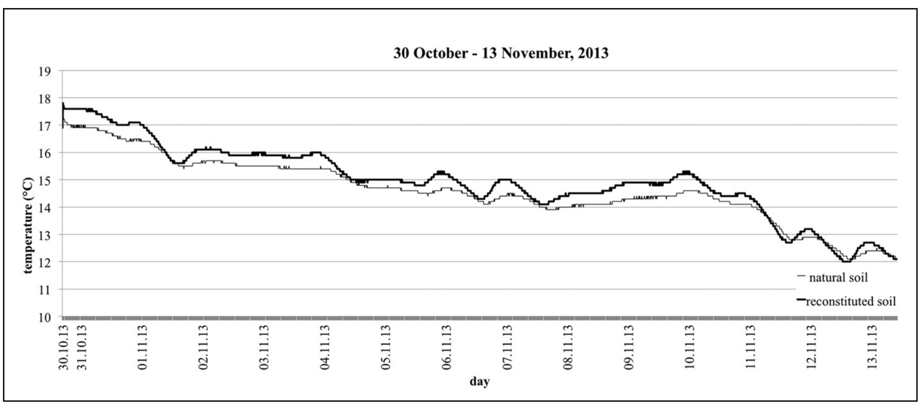

Fig. 7 - Soil temperature fluctuation in November.
Fig. 7 - Andamento temperature nel mese di novembre.

temperature was 26.5 °C and thermal excursion 3.7 °C. In Fig. 6 the summer diurnal cycle referring to July, 18 it could be seen a high daily excursion but only in natural soil.
In the first 13 days of November the mean air temperature was 12.1 °C, max temperature 17.9 °C, min temperature 5.5 °C, 8 days of rain with a total of 21.4 mm rain. The temperature trend was similar for all soils, Fig. 7.
In the first 10 days of January the mean air temperature was 5.5 °C, max temperature 12.3 °C, min temperature -1.6 °C, 11 days of rain with a total of 33.8 mm rain. The reconstituted soil, Fig. 8, had always higher temperature than the

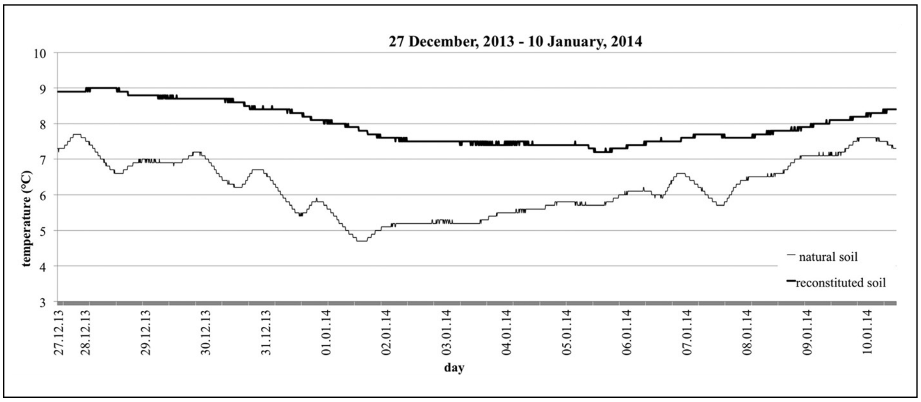

Fig. 8 - Soil temperature fluctuation in January.
Fig. 8 - Andamento temperature nel mese di gennaio.

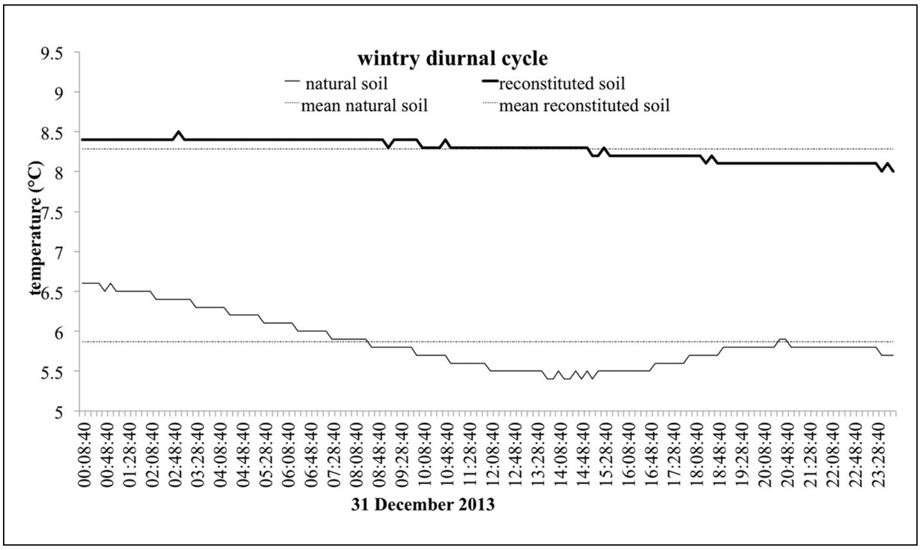

Fig. 9 - Soil wintry diurnal cycle.
Fig. 9 - Ciclo diurno invernale.

natural one. Mean reconstituted soil temperature was 8 °C and thermal excursion 0.2 °C, mean natural soil temperature was 6.2 °C and thermal excursion 0.6 °C. The major temperature differences between soils was observed in the coldest days - as January, 1 - when the natural soil lost heat while the reconstituted one held it. In Fig. 9 the soil wintry diurnal cycle referring to December, 31, a daily excursion could be seen but only in natural soil. This could probably due to lack of rainfall that prevented in general seheat loss.

4. DISCUSSION

The reconstituted soils had less temperature fluctuations than natural one. Soil thermal properties are influenced mostly by particle size distribution, water content and bulk density (Rubio *et al.*, 2011) and porosity. The size distribution of the porosity of a soil is largely influenced by the presence of the organic matter, which has the ability to make relatively stable aggregates between the particles. The aggregates behave like real particles. For this reason the real soil porosity can be very different from that deduced on the particle size distribution by laboratory measurements of soil samples in which this aggregation may have been partially destroyed (Raimo and Napolitano, 2002).
The particle size and distribution have an effect on the manner in which the moisture is held (Singh and Devid, 2000). Soil water content has an important role in determining soil thermal properties, because the conduction through the soil is largely electrolytic (Van Rooyen and Winterkorn, 1957).
Water and/or air occupy the soil pores; the air thermal conductivity and heat capacity are

lower than water. In a moist soil the heat transport is fast but more energy is required to change the temperature by 1 K in a 1 m^3 layer. Water delays warming because part of absorbed sun energy is used for evaporation. Moist soil heat capacity is high but besides a particular water contents thermal diffusivity is reduced, so with the same energy availability a moist soil hold more heat – warms less (in the spring) and cools more slowly (in the fall) – than a dry one. Low air heat capacity makes porosity more affecting thermal diffusivity at the same water content: soils with high porosity warm and cool more slowly.

Reconstituted soil had more volumetric water content at different suctions, organic carbon (43.9 gkg^{-1} reconstituted soil, 12.1 gkg^{-1} natural soil) and porosity (49 % reconstituted soil, 32 % natural soil) than natural one. ANOVA confirmed these differences, proving that the type of treatment had a positive effect on these soil parameters. In this way it could be justified their different thermal properties: the reconstituted soil preserved a higher temperature in the winter months and lower in the summer ones flattening also the day-night temperature fluctuations.

5. CONCLUSION

The less reconstituted soil temperature fluctuations than natural degraded one are justified by the best chemical-physical parameters due to the reconstitution treatment. These results together with others, now studying, show that the reconstitution technology can help to counteract the land degradation.

REFERENCES

Abdul Rahim N., Baharuddin K., Azman H., 1986. Soil temperature Regimes under mixed dipterocarp forests of peninsular Malaysia. Pertanika 9(3) 1986, pp. 277-284.

De Vries D.A., 1952: The thermal conductivity of soil. Meded. Landbouwhogesch, Wageningen, p. 52.

De Vries D.A., 1963. Thermal properties of soils. In Physics of Plant Environment (Van Wjik W.R., ed) 210-235. North-Holland, Amsterdam.

EC European Commission: Com (2006 a) 232 – Proposta di Direttiva del parlamento europeo e del Consiglio che istituisce un quadro per la protezione del suolo e modifica la direttiva 2004/35/CE.

EC European Commission: Com (2006 b) 231 - Comunicazione della Commissione al Consiglio, al Parlamento europeo, al Comitato economico e sociale europeo e al Comitato delle regioni. Strategia tematica per la protezione del suolo.

EC European Commission: Com (2012) 46 - Relazione della Commissione al Parlamento europeo, al Consiglio, al comitato economico e sociale europeo e al Comitato delle regioni. Attuazione della strategia tematica per la protezione del suolo e attività in corso.

Farouki T.O., 1981. Thermal properties of soils. CRREL Monograph 81-1. Cold Regions Research and Engineering Laboratory, Hanover, NH.

Floccia F., Jacomini C., 2012. ISPRA, Quaderni – Natura e Biodiversità n. 4/2012.

Lal R., Shukla M.K., 2004. Principles of soil physicis. Marcel Dekker inc. New York, Basel.

Leirós M.C., Trasar-Cepeda C., Seoane S., Gil-Sotres F., 1999. Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biology and Biochemistry 31 (1999) pp. 327-335.

Manfredi P., Tassi D., Cassinari C., 2012. Confronto tra dati produttivi di mais coltivato su terre ricostituite e terre naturali, EQAbook 2012/1, pp. 69-80.

MATTM - Ministero dell'Ambiente e della tutela del territorio e del Mare, 2010. La strategia Nazionale per la Biodiversità.

Nidal H.A., 2003. Thermal properties of soil as affected by density and water content. Biosystem Engeneering, 86, 97-101 DOI 10.1016/S1537-5110(03)00112-0.

Perini L., Salvati L., Ceccarelli T., Sorrenti S., Zitti M., 2008. La desertificazione in Italia. Processi, indicatori, vulnerabilità del territorio. Bonanno editore. ISBN 978-88-7796-422-9: pp. 192.

Raimo F., Napolitano A., 2002. Approccio alla valutazione granulometrica ed idrologica di vari suoli. Il tabacco,10, pp. 9-22.

Rubio M. C., Josa R., Ferre F., 2011. Influence of the hystertic behavior on silt loam soil thermal properties. Open Journal of Soil Science, 1, pp. 77-85. doi 10.4236/ojss.2011.1311.

Singh D. N. and Devid K., 2000. Generalized relationship for estimating soil thermal resistivity. Experimental Thermal and Fluid Science, vol. 22, n. 3-4, pp. 133-143. doi :10.1016/S0894-1777(00)00020-0.

Tenge A.J., Kaihura F.B.S., Lal R., Singh B.R., 1998. Diurnal soil temperature fluctuation for different erosion classes of an oxisol at Mlingano, Tanzania. Soil & Tillage Research 49 (1998) pp. 211-217.

United Nations General Assembly A/AC 241/27, 1994. Elaboration of an international convention to combat desertification in countries experiencing serious drought and/or desertification, particularly in Africa.

Van Rooyen M. and Winterkorn H. F., 1957. Theoretical and practical aspects of the thermal conductivity of soils and similar granular systems. Us HighwayResearch Board Bulletin, vol. 159, pp. 58-135.

Wierenga P.J., Nielsen D.R., Hagan R.M., 1969. Thermal properties of soil based upon field and laboratory measurements. Soil Science Society of America Proocedings, 33, 354-360.

Yadav M.R., Saxena G.S., 1973 Effect of compactation and moisture content on specific heat and thermal capacity of soils. Journal Indian Society of Soil Science, 21 129-132.

http://www.lifeplusecosistemi.eu